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CONCLUSIONS

The results show that the modified-rectangular citrus box is equally suitable for use in air- and tight-stack patterns used mostly in unitization. In tight-stack patterns in the USDA van, far greater airflows are obtainable through the modified box than the conventional boxes in conventional trailers, and thus field heat is removed much faster and the contents are cooled more rapidly. The modified box is especially suited for use in the USDA van, which provides an improved method of interfacing the circulating cooled air at the bottom of the load.

Compression tests indicated that the modified box was equally as strong as the conventional boxes tested.

Although box damage resulting from overhead weight crushing was not a problem in these shipping tests, loading boxes in a tight-stack pattern utilizes their structural strength more effectively to protect the contents. An air-stack pattern does not fully utilize structural strength and increases the likelihood of box failure with damage to contents. Using a tight-stack pattern is also simpler and faster than an air-stack pattern and can result in greater payloads. Tight-stack stowage patterns increase utilization of available vehicle cube by as much as 10 percent over the air-stack patterns. Increased utilization of vehicle cube increases the payload, which in turn means more efficient utilization of diesel fuel. For example, an increase of vehicle cube by 10 percent would mean that the equivalent of 10 loads of citrus could be transported in 9 refrigerated trailer loads.

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A MODIFIED FIBERBOARD CITRUS BOX FOR CONVENTIONAL REFRIGERATED TRAILERS AND USDA EXPERIMENTAL VAN CONTAINER

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AGRICULTURE

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ABSTRACT

McDonald, Roy E., Thomas H. Camp, and William F. Goddard, Jr. 1979. A modified fiberboard citrus box for conventional refrigerated trailers and USDA experimental van container. U.S. Department of Agriculture, Marketing Research Report No. 1100, 12 pp.

A modified 7/10-bushel (24,667-cm^3) corrugated fiberboard citrus box was tested and compared with conventional boxes of the same style. It has a greater ventilation area than the conventional boxes, and all openings are in the top and bottom panels.

The advantages of the modified box, as identified in this study, are as follows:

(1) It was equally suitable for use in air- and tight-stack patterns used mostly in unitization.

(2) In tight-stack patterns, greater airflows were obtainable through the modified box than the conventional boxes in simulated loads with a vertical airflow system.

(3) Compression tests indicated that the modified box was equally as strong as the conventional boxes tested.

(4) The modified box is especially suited for use in available conventional refrigerated trailers and the USDA van container, in which the cooled air is delivered to the bottom for circulation upward through a tightly stacked load.

(5) Field heat could be removed much faster from citrus when the fruit was in the modified box and shipped in the USDA van container with vertical w than when shipped in conventional boxes in conventional refrigerated rs.

Citrus, fiberboard citrus box, shipping containers, refrigerated trailers, USDA experimental van containers, cargo-air temperatures.

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CONTENTS

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A MODIFIED FIBERBOARD CITRUS BOX
FOR CONVENTIONAL REFRIGERATED TRAILERS AND
USDA EXPERIMENTAL VAN CONTAINER

By Roy E. McDonald, Thomas H. Camp, and William F. Goddard, Jr. 1/

Maintaining the quality of fresh citrus during shipment from production area to distant markets and during storage and marketing is a problem of considerable interest to growers and shippers. Many interrelated environmental factors cause deterioration of fresh citrus, resulting in physiological breakdown, injury, and attack by decaying-producing fungi. If citrus is to be adequately protected throughout the marketing channels, proper temperature maintenance is essential.

The value of refrigeration in extending the shelf life of citrus has long been recognized. Today, 97.7 percent of Texas citrus is shipped to domestic markets in mechanically refrigerated highway trailers. 2/

Shipping containers for citrus are rectangular, corrugated fiberboard boxes, which are made in several styles. One type is a full-telescope, half-slotted box. Its inner and outer flaps, which do not meet at the center, form a rectangular ventilation opening in both the cover (top) and the body (bottom). The top section completely covers the bottom section. Another type is a full-telescope box constructed with extra thicknesses of corrugated fiberboard for the sides and ends. The top section also completely covers the bottom section. The most common shipping container for Texas citrus is the 7/10-bushel (24,667-cm^3) corrugated fiberboard box. It is used for 54 percent of all fresh grapefruit shipments and 41 percent of all fresh orange shipments from Texas. 3/ The boxes used by the citrus industry at the time of this study usually had rectangular or circular ventilation openings in the top, bottom, and side panels, as described in table 1.

1/ Respectively, research horticulturist, European Marketing Research Center, Science and Education Administration, Rotterdam, the Netherlands; agricultural marketing specialist, Transportation and Marketing Research Unit, SEA, College Station, Tex. 77840; and mechanical engineer (retired), U.S. Horticultural Research Laboratory, SEA, Orlando, Fla. 32803.

2/ U.S. Department of Agriculture, Agricultural Marketing Service. Fresh fruit and vegetable shipments, calendar year 1972. FVUS-6, 59 pp. 1972.

3/ Connolly, C., Evans, R., and Moore, R. Texas fresh citrus shipments by containers, 1972-73. Tex. Agr. Expt. Sta. Res. Rpt. MRC 73-4, 94 pp. 1974.

Table 1.--Description of ventilation openings in shipping boxes for Texas citrus fruit 1/

Sections of box	Box by type of ventilation opening 2/								
	Conventional-rectangular			Conventional-circular			Modified-rectangular		
	Opening	Size of opening	Ventilated area	Opening	Size of opening	Ventilated area	Opening	Size of opening	Ventilated area
	Number	In	In^2	Number	In	In^2	Number	In	In^2
Cover:									
End panels (2)--	---	---	---	---	---	---	---	---	---
Side panels (2)-	4	3/4 X 2-3/4 (1.9 X 7.0)	7.8 (50.3)	4	1 (2.5)	3.1 (20.0)	---	---	---
Top panel-------	2	13/16 X 3-3/8 (2.1 X 8.6)	5.4 (34.8)	6	1-3/8 (3.5)	8.9 (57.4)	8	1 X 3 (2.5 X 7.6)	22.3 (143.9)
Body:									
Bottom panel----	2	5/8 X 3-3/8 (1.6 X 8.6)	4.1 (26.4)	6	1-3/8 (3.5)	8.9 (57.4)	8	1 X 3 (2.5 X 7.6)	22.3 (143.9)
Total----------	8	---	17.3 (111.6)	16	---	20.9 (134.8)	16	---	44.6 (287.8)
Ventilated surface area (percent)--	---	---	1.8 (11.6)	---	---	2.1 (13.5)	---	---	4.5 (29.0)

1/ Outside box dimensions (inches): Length, 17-7/8; width, 11-1/2; height, 9-3/4; or 983.93 square inches of surface area (45.4, 29.2, 24.8 cm, or 6,348.3 cm^2, respectively).

2/ Centimeter and square centimeter measurements in parentheses.

When loaded in refrigerated trailers or van containers, these shipping boxes are placed in an air-stack pattern[4/] so that cool air can circulate around and through the boxes. Open- or air-stack stowage patterns reduce load density and lower utilization of available vehicle loading cube by 8 to 10 percent, which results in higher refrigeration and freight costs per box of fruit. Air-stack patterns can introduce instability into the load, causing disarrangement by shifting of boxes, which blocks air channels and frequently results in shipping box and product damage. Although conventional boxes have proved satisfactory when air-stacked, the ventilation openings on the side and end panels are blocked in tight-stacked loads. The patterns of ventilation openings in the conventional boxes do not lend themselves to tight-stack patterns used mostly in unitization.

To develop a box that could be tight-stacked and provide proper ventilation on a pallet or slipsheet, tests were made on a modification of the conventional design. The modified box has ventilation openings only in the top and bottom of the box (fig. 1), whereas the conventional box typically has openings in the top, bottom, and sides.

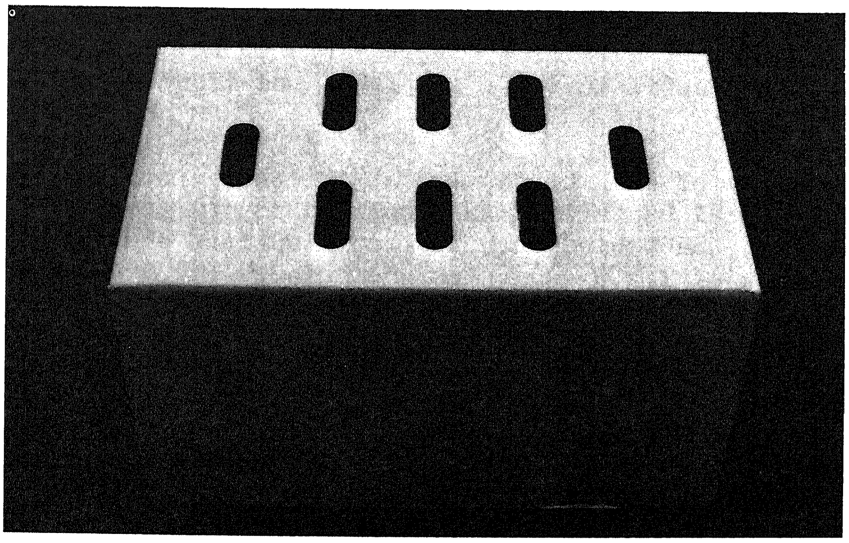

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Figure 1.--Modified corrugated citrus box with ventilation openings in top.

This modified 7/10-bushel (24,667-cm^3) corrugated fiberboard citrus box was tested for its suitability in air-stack and tight-stack or register loading patterns used mostly in unitization. It was also tested in the USDA experimental refrigerated van container, hereafter referred to as USDA van, which incorporates a lateral air delivery concept for vertical airflow through the load.

4/ Hinds, R. H., and Robertson, J. K. A better loading pattern for trailer shipments of citrus fruit. U.S. Dept. Agr. Mktg. Res. Rpt. 715, 8 pp. 1965.

LATERAL AIRFLOW DELIVERY DESIGN OF USDA VAN

The USDA van, 5/ designed by the U.S. Department of Agriculture in cooperation with private industry, was used in five shipping tests from the Rio Grande Valley of Texas to California and to midwestern destinations.

The diesel- or electric-powered refrigeration unit is a standard Carrier Transicold Model 69ND 35-248 with 66 percent unloading capability. It has a cooling capacity of 15,000 Btu per hour (3,780 kcal/h) at 0° F (-17.8° C) or 30,000 Btu per hour (7,560 kcal/h) at 35° (1.7°) and is thermally rated at 9,000 Btu per hour (2,268 kcal/h) at 100° (37.8°) temperature differential.

Two discharge ducts, one on each side of the ceiling, supply the sidewall flues. Each duct is 6 inches (15.2 cm) deep and is tapered from 2 feet (61 cm) at the front to a 10-inch (25.4-cm) width at the rear. Both are attached to the front wall at the blower discharge outlet, run the entire length of the van, and terminate at the rear doors. Tapering is necessary in the USDA van because a standard, commercially available refrigeration unit was used that has two discharge outlets, one on each side of the van. The outlets are located about one-third the distance in from the sidewall and separated at the centerline by about 2 feet (61 cm). The ducts taper to provide a gradual transition and constant pressure, but a short baffle or diverter had to be inserted in the discharge outlet to insure sufficient air supply to the front 5 feet (152.4 cm) of cargo space.

The free-face area of each of the two air discharge outlets on each side of the van's longitudinal centerline is about 0.5 square foot (464.5 cm^2). There are two blowers, one behind each discharge outlet, and each blower delivers air at a rate of 1,500 cubic feet per minute (42.5 m^3/min) at a static pressure of 2.2 inches (5.6 cm) of water. The ceiling ducts and sidewall flues have a total pressure drop of 0.5 inch (1.3 cm). The net static pressure available at the interface between the cargo and the floor is about 1.5 inches (3.8 cm). Volume at the intersection of the sidewall flue and the floor is about 35 cubic feet per minute (1.0 m^3/min) per foot (30.5 cm) of floor length, or about 8.5 cubic feet per minute per square foot (0.024 $m^3/min/m^2$) at the interface of the floor and the cargo box.

The principal difference between the USDA van and conventional refrigerated trailers is the air circulation system. In the USDA van, refrigerated air passes through enclosed ducts at the ceiling, down the sidewall flues, through
ts, which run crosswise in the van, then up through the load,
r return at the top of the front bulkhead. 6/ In conventional
ated air moves from an air duct above the load, down through
or extrusions, which run lengthwise in the trailer, and back
at the bottom of the front bulkhead. The USDA van has
, tangential air blowers capable of producing 2.2 inches

, P. L. Engineering better interfacing of the load, the
, and the refrigeration unit for improved transportation.
tric. Proc. 1: 288-293. 1977.
. F. The floor - a common denominator for refrigerated
. Internatl. Inst. Refrig. - Comn. D2, Wageningen, the
9-49. 1974.

(5.6 cm) of static head pressure as compared with 0.75 inch (1.9 cm) of static head pressure produced by the conventional refrigeration unit's air blowers.

TEST METHODS

During 2 shipping seasons, 17 shipping tests were monitored to compare transit temperatures of citrus in conventional and modified boxes. The shipping tests were divided into three phases as follows: In phase 1, conventional boxes in air-stack patterns were compared with modified boxes in tight-stack or register patterns in four paired shipments in conventional refrigerated trailers. In phase 2, modified boxes were compared when stowed in air- and tight-stack patterns in two paired shipments in conventional refrigerated trailers. In phase 3, temperatures were monitored in five shipments of modified boxes loaded in tight-stack patterns in the USDA van. Air- and tight-stack loading patterns are shown in figure 2.

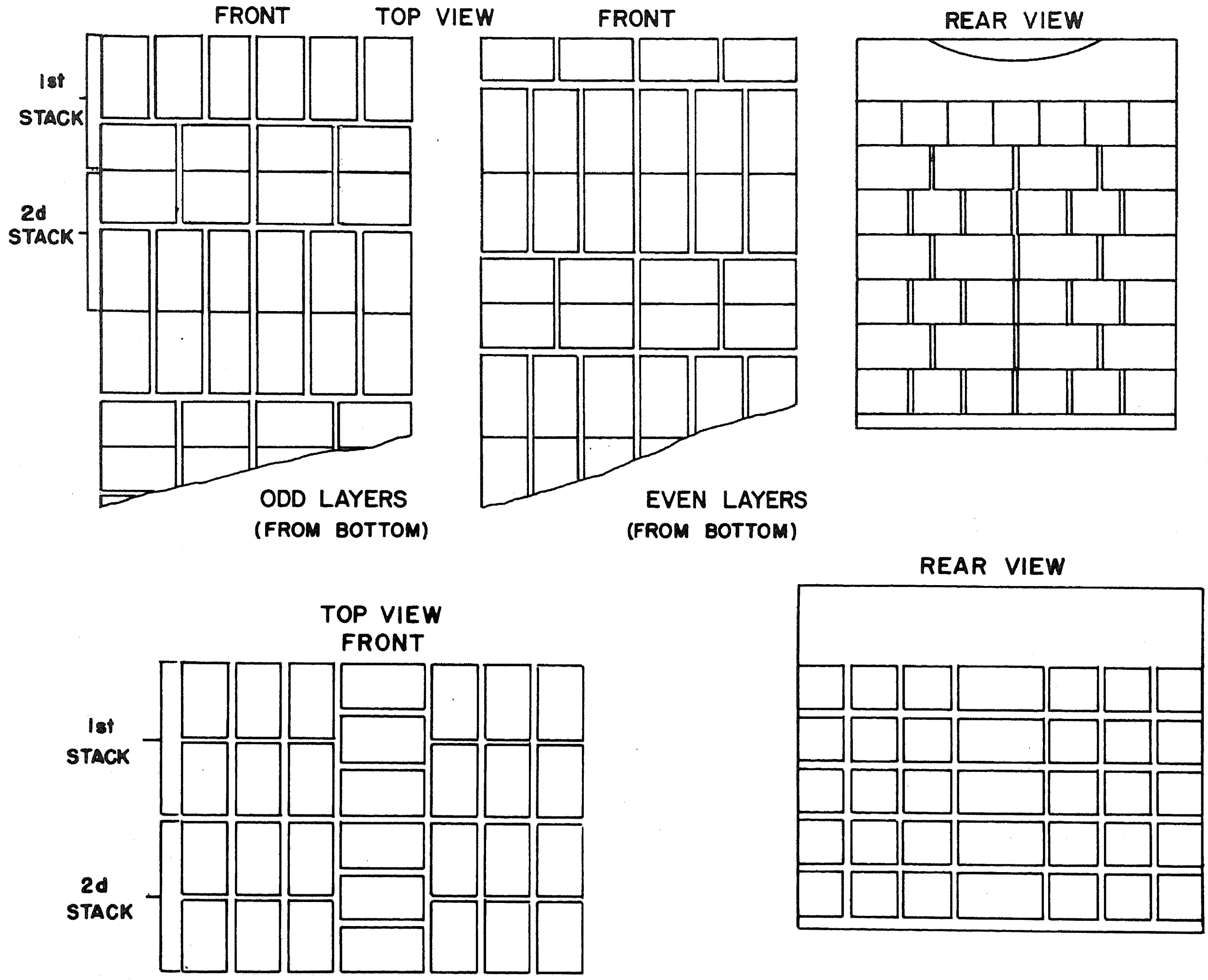

Figure 2.--Loading arrangement of citrus boxes: Above, in air-stack pattern (6 X 4 modified bonded block); below, in tight-stack or register pattern.

The paired shipments in phases 1 and 2 were conducted in conventional refrigerated trailers with similar refrigeration, insulation, and dimensions. The pairs of trailers were loaded at the same packinghouse on the same day and were bound for the same destination over the same route.

During shipment, citrus temperatures and cargo-air temperatures were monitored with mechanical-type temperature recorders or manually with thermocouple sensors. For the paired shipments in phases 1 and 2, one mechanical-type temperature recorder was placed in the plenum and three of them inside citrus boxes interspaced throughout the load (fig. 3, above). For phase 3, shipments were instrumented using thermocouple sensors throughout the load (fig. 3, below). Cables were run from the interior of the trailers and van

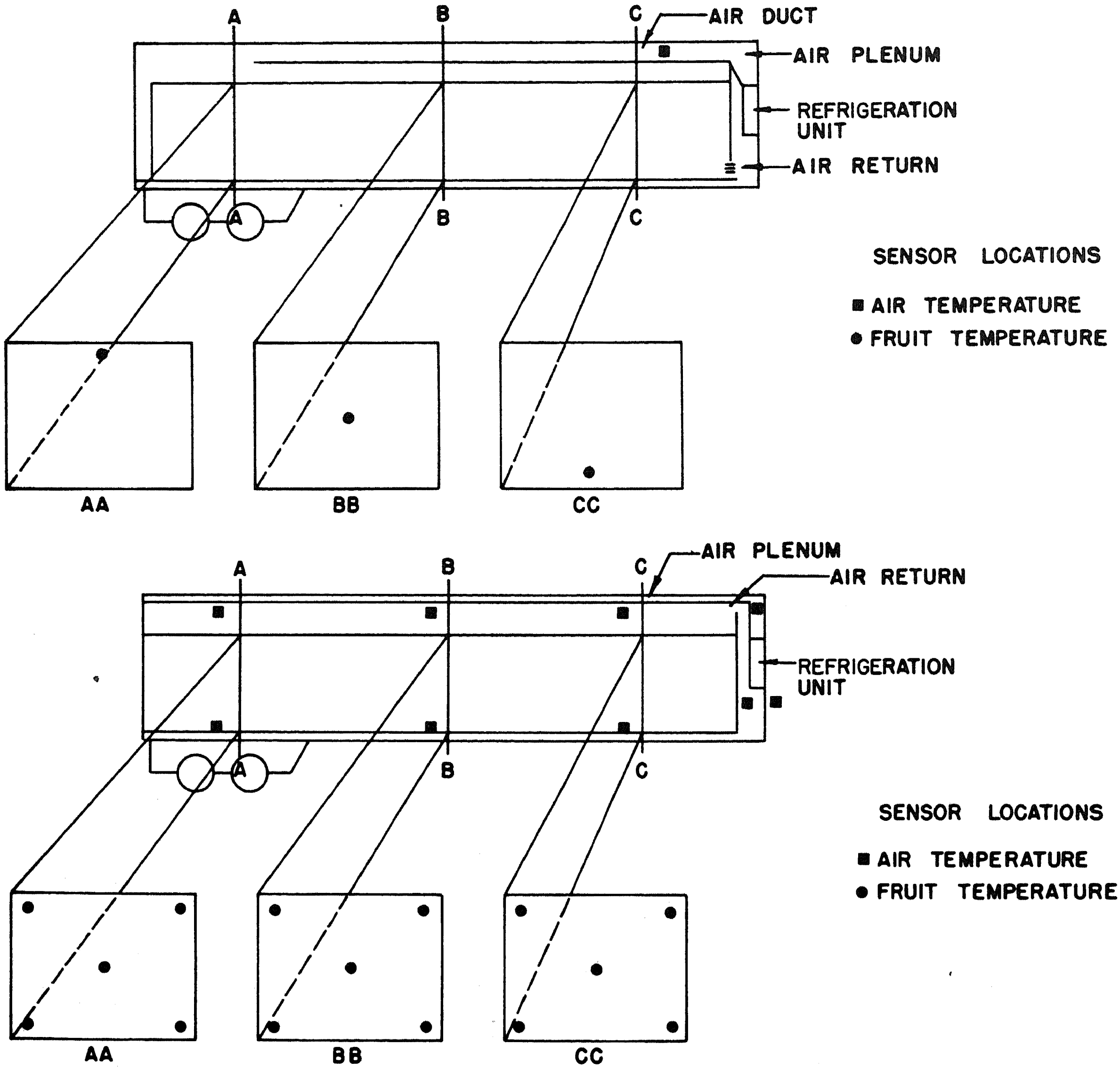

Figure 3.--End views through load of approximate location of mechanical-type temperature recorders used in conventional refrigerated trailers (above) and of 24 thermocouple sensors used in USDA van (below) to monitor citrus and cargo-air temperatures.

through a front floor drain to the tractor interior, where wires were connected to a switchbox and null potentiometer. Readings were taken every 4 hours commencing with closing the vehicle doors and ending with their opening at destination.

Air movement was measured by a hot-wire anemometer. Airflow was compared between conventional and modified boxes when both were tight-stacked in the USDA van at Orlando, Fla.

Compression tests of two types of conventional boxes and the modified box were made by the Forest Products Laboratory, Madison, Wis. The corrugated fiberboard shipping boxes tested were obtained from the same manufacturer and assembled on the same equipment. Seventy-five boxes were shipped in a large master container or bulk bin to the Forest Products Laboratory. All arrived undamaged and were used in the various compression tests.

Each of the 7/10-bushel (24,667-cm^3) corrugated fiberboard (single wall) 7/ boxes studied was two-piece, full-telescope, with inside dimensions of 16-1/2 X 10-3/4 X 9-1/2 inches (41.9 X 27.3 X 24.1 cm). The cover and body joints of all cartons were secured with moisture-resistant adhesives, and all were assembled with an automatic machine. Covers were constructed of 250-pound (113.4-kg) container board (42-33-69) 8/ and bodies of 275-pound (124.7-kg) container board (69-33-69). Bursting strength 9/ was 250 pounds (113.4 kg) for the cover and 275 pounds (124.7 kg) for the body.

RESULTS AND DISCUSSION

Product Temperature Differences in Shipping Tests

Table 2 gives cooling coefficients calculated from temperatures monitored in the shipping tests as explained in Test Methods. Cooling coefficients are used to express the results of the comparative shipping tests, as differences in initial product temperature and temperature of cooling air are accounted for.

For the four paired shipments in phase 1, cooling coefficients averaged 0.023 for conventional boxes in air-stack patterns compared with 0.020 for modified boxes in tight-stack patterns. For the two paired shipments in phase 2, cooling coefficients averaged 0.018 for modified boxes in air-stack patterns compared with 0.019 for modified boxes in tight-stack patterns. These data

7/ Also known as double face; the structure formed by one corrugated inner member glued between two flat facings.

8/ A single-wall combination such as 42-33-69 would indicate that the two facings and the corrugating medium weigh 42, 69, and 33 pounds per thousand square feet (19.1, 31.3, and 15 kg per 92.9 m^2), respectively.

9/ Bursting strength (Mullen): Measurement of the resistance of a material to bursting expressed in pounds per square inch (kilograms per square centimeter). The test is made on a Mullen tester.

Table 2.--Cooling coefficients 1/ calculated in citrus loads comparing conventional and modified boxes and 2 stacking patterns in conventional refrigerated trailers and USDA van

Vehicle and box	Cooling coefficients for indicated stacking pattern and shipment number										
	Air stack					Tight stack					
	1	2	3	4	Average	1	2	3	4	5	Average
Conventional trailers:											
Conventional------	2/ 0.025	0.019	0.034	0.016	0.023	---	---	---	---	---	---
Modified----------	---	---	---	---	---	0.025	0.022	0.016	0.018	---	0.020
Do--------------	.017	.020	---	---	.018	.017	.021	---	---	---	.019
USDA van:											
Modified----------	---	---	---	---	---	.0102	.097	.064	.069	0.067	.079

1/ Calculated as product temperature reduction in degrees per hour divided by average temperature difference between product and coolant air.

2/ Calculated using average product temperatures for all test locations in load.

suggest that cooling rates are approximately the same for conventional boxes in air-stack patterns and modified boxes stowed in either the air- or tight-stack patterns.

In phase 3, cooling coefficients averaged 0.079 when modified boxes were loaded in tight-stack patterns in the USDA van (table 2). Cooling coefficients calculated in citrus loads in the USDA van were about four times better than those calculated in conventional trailers, irrespective of box type and stacking patterns.

Suggested reasons for these significantly higher cooling coefficients in the USDA van are (1) the quantity of air delivered in the USDA van is 3,000 cubic feet per minute (85 m^3/min) compared with 2,000 to 2,500 cubic feet per minute (56.6 to 70.8 m^3/min) in conventional trailers and (2) the static pressure of air as it enters the load in the USDA van is 1.5 inches (3.8 cm) of water compared with 0.2 to 0.3 inch (0.5 to 0.8 cm) of water in conventional trailers. Thus, the refrigeration capacity of the USDA van is more efficiently utilized.

Airflow

Airflow comparisons were made in stationary tests between the conventional and modified boxes under simulated conditions with both types stowed in a tight-stack pattern in the USDA van. The boxes were filled with plastic balls approximating a size 80 orange to simulate a load of citrus. Airflow was measured for volume at specific locations throughout a stack, as shown in figure 4. In these simulated loads, airflow through the modified boxes was eight times greater than through the conventional boxes. The modified boxes have a greater total top and bottom ventilated area (table 1).

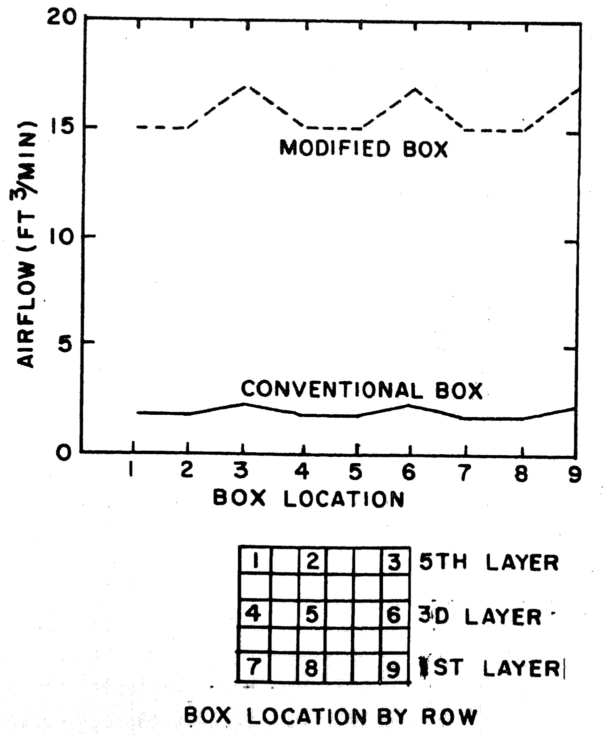

Figure 4.--Airflow measurements using conventional and modified boxes in tight-stack pattern in USDA van with simulated load of size 80 oranges.

Compression Tests

Compression tests were made on sample lots of conventional boxes (conventional-rectangular and conventional-circular) and the modified box (modified-rectangular). The three shipping boxes are shown in figure 5 and the compression values in table 3.

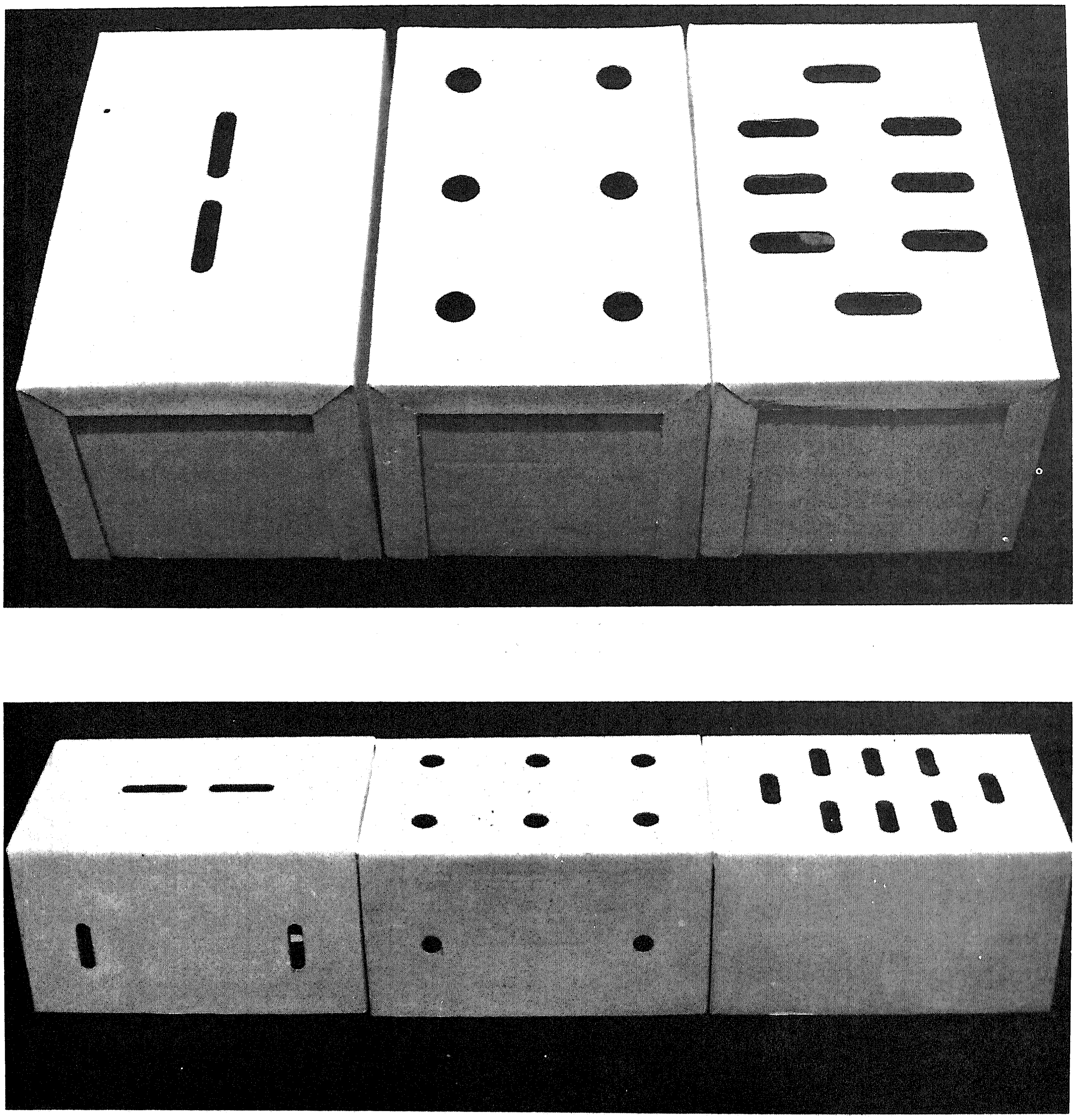

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Figure 5.--Citrus boxes tested for compression strength: Above, covers (top and end view); below, bodies (bottom and side view). Left to right, conventional boxes with rectangular and circular ventilation openings and modified box with rectangular openings.

Table 3.--Compression resistance values of citrus boxes 1/

Type of box	Maximum resistance values 2/ in-- Top-to-bottom compression	Side-to-side compression	End-to-end compression
	Pounds	Pounds	Pounds
Conventional-rectangular---	1,772 b (803.7)	573 a (259.9)	310 b (140.6)
Conventional-circular------	2,005 a (909.5)	538 ab (244.0)	391 a (177.4)
Modified-rectangular-------	1,883 ab (854.1)	513 b (232.7)	344 b (156.0)

1/ Average of 7 replications. Comparable values with no letter in common are statistically different at 1-percent confidence level.
2/ Kilogram values in parentheses.

Because of certain uncontrolled variables in the box fabrication process, such as board production, forming, printing, and gluing, a statistical analysis was made to ascertain whether the compression test values were significantly different. This analysis indicated that in all three directions the average compression strengths were statistically different at the 1-percent confidence level.

The following results are indicated: In top-to-bottom compression, the conventional-circular was significantly better than the conventional-rectangular box, but the modified box did not differ from either of the two conventional ones. In side-to-side compression, the conventional-rectangular was better than the modified-rectangular box, but the conventional-circular box was not significantly different from either of the other two. In the end-to-end compression, the conventional-circular was significantly better than the conventional-rectangular and modified-rectangular boxes.

The greater compression resistance of the conventional boxes on the horizontal plane, i.e., side-to-side and end-to-end, is of little practical value since the main compression the box has to resist is from top to bottom. The boxes must sustain overhead weight when stacked on pallets, stowed in transport vehicles, and held in refrigerated warehouses or retail outlets, where they are generally stored vertically in tight-stack patterns.

Although the analysis indicates some differences, there is a question whether or not these differences are significant from the practical point of view. For example, one might logically anticipate that the modified-rectangular box would perform better than the others in top-to-bottom compression because

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it has ventilation openings only in the top and bottom, whereas the two conventional boxes have openings in the top, bottom, and sides; however, such was not the case, because the modified-rectangular box was no different from the other two. This tends to support the concept that ventilation or hand openings probably do not significantly affect compressive strength of corrugated fiberboard boxes 10/ within the design parameters prevalent at this time.

CONCLUSIONS

The results show that the modified-rectangular citrus box is equally suitable for use in air- and tight-stack patterns used mostly in unitization. In tight-stack patterns in the USDA van, far greater airflows are obtainable through the modified box than the conventional boxes in conventional trailers, and thus field heat is removed much faster and the contents are cooled more rapidly. The modified box is especially suited for use in the USDA van, which provides an improved method of interfacing the circulating cooled air at the bottom of the load.

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